The Ozone Mapping and Profiler Suite-Assimilation Experiment (OMPS-AE)

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Abstract - **The major weather services worldwide have concluded that longer-term tropospheric weather forecasting will require a more realistic treatment of the stratosphere. A major research effort is now underway at the Naval Research Laboratory (NRL) to extend the Navy Operational Global Atmospheric Prediction System (NOGAPS) into the stratosphere. The extended NOGAPS must assimilate and forecast ozone because absorption of UV radiation by ozone provides the primary energy input into the stratosphere. This energy input is a major driver of the stratospheric circulation, which, in turn, significantly affects the large-scale movement of surface weather systems. Operational ozone data for the extended NOGAPS will be obtained from the NPOESS Ozone Mapping and Profiler Suite (OMPS). OMPS consists of a nadir-viewing instrument that measures the ozone total column and profile (similar to TOMS & SBUV/2), and a limb-viewing instrument designed to measure the ozone profile between the tropopause and 60 km.**

OMPS-like ozone data are needed for developing and testing the extensions to NOGAPS. We have proposed an early flight of OMPS, OMPS-AE (OMPS-Assimilation Experiment), to provide such data. We are also exploring techniques for merging and extending data from existing satellite measurements of ozone profiles to produce 3D global ozone fields. In the future we will conduct experiments in which the global ozone fields from OMPS-AE or the data fusion experiments will be assimilated into the extended NOGAPS, with the aim of evaluating assimilation methodologies and increased forecasting skill. The ultimate goal of the experiment is the development of a new operational forecast system with the capability of utilizing the OMPS ozone data immediately when it becomes available after the launch of the first NPOESS satellite.

I. Longer Term Tropospheric Forecasts Need Daily Operational Data on Stratospheric Ozone

Present-day numerical weather prediction demonstrates a useful level of skill for forecasts up to five or six days in advance. But many applications require slightly longer forecasting intervals: nine to ten days. Considerable preparation is needed before docked ships can evacuate a port threatened by a hurricane. Agriculture, long-range transportation, and flood control would also benefit from longer-term forecasts.

The errors in present-day forecasts are often particularly large in the vicinity of jet streams. At mid and high latitudes the jet streams play a major role in the formation and steering of tropospheric weather systems, including large-scale thunderstorm complexes and hurricanes, so improved forecasting of jet streams should lead to improved long-term forecasting of tropospheric weather.

The large forecast errors near jet streams suggest that an improved treatment of the stratosphere will be a key ingredient in any increase of the useful term of tropospheric forecasts. Numerical studies bear this out [1]. Therefore major weather services worldwide are extending their data assimilation and forecasting codes to provide a more realistic treatment of the stratosphere. Weather services making such extensions include ECMWF, UKMO, NESDIS and DoD.

A crucial component of a more realistic treatment of the stratosphere must be the use of daily measurements of the ozone distribution instead of an ozone climatology. Ozone plays a crucial role in the series of intricate feedback mechanisms that dynamically link the troposphere and the stratosphere. Absorption of solar UV by ozone provides the primary energy input to the stratosphere, heating the region between 30 and 300 mb (24 to 9 km). This heating is largely responsible for the global temperature inversion, which is in fact the stratosphere. In addition, the 9.6 µm absorption band of ozone significantly cools the stratosphere and lower mesosphere between 0.4 and 10 mb (55 to 31 km). The distribution of ozone in the stratosphere thus strongly affects the temperature and circulation structure of the stratosphere, which, in turn, strongly affects the large-scale movement of surface weather systems.

The global distribution of ozone on the 350K isentropic surface (about 12 km) is shown in Fig. 1. It illustrates why daily data on ozone must be used instead of climatology. A climatology would be zonally symmetric, and would not even include some of the latitude variations that would survive after zonally averaging Fig. 1.

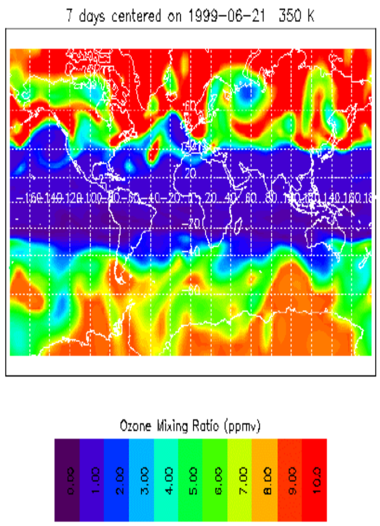

Fig. 1. Ozone field on June 21, 1999 on the 350K isentropic surface, obtained from the UKMO potential vorticity field together with a running 7-day average correlation between ozone mixing ratio and potential vorticity on the same isentropic surface derived from POAM III, SAGE II, and HALOE ozone data. The technique is an extension of that discussed by [2].

The influence of stratospheric ozone upon tropospheric weather is not limited to its effect on jet streams. By affecting the temperature structure and thence the large-scale winds in the stratosphere, ozone affects whether the stratosphere reflects upward-propagating planetary waves. This mechanism leads to a host of effects on tropospheric weather [3]. For example, when the wintertime polar stratospheric vortex is strong, the southward propagation of planetary waves in the troposphere is enhanced. Also, a strong wintertime polar stratospheric vortex causes hemisphere-scale alterations in the structure of wave number 1 waves in the troposphere.

In addition to enabling improved forecasts of the temperature field in the stratosphere, the use of daily measurements of the ozone field instead of climatology should also enable improved diagnostic techniques. In the lower stratosphere and below, ozone approximates a passive tracer, because at these altitudes sunlight is weak enough (in the absence of activated chlorine) to allow a long photochemical lifetime compared to the time scale for transport by the winds. Hence the ozone field bears the imprint of fronts and air masses, and can be used to detect and delineate such features [4].

II. The Upward Extension of NOGAPS

DoD's principal global weather forecasting code is the Navy Operational Global Atmospheric Prediction System (NOGAPS). NOGAPS was developed by NRL/Monterey, and is operated by the Fleet Numeric Meteorological and Oceanographic Center (FNMOC).

A major research effort is now underway at the Naval Research Laboratory (NRL) to extend NOGAPS to more realistically depict the stratosphere and mesosphere. The current operational version of NOGAPS has 24 levels. There is a sponge layer at 5 mb (about 34 km) to damp out artifacts due to interactions with the upper boundary of the model. This results in the utility of NOGAPS' forecasts becoming less meaningful as that altitude is approached. An initial extension will bring NOGAPS to 36 levels, with a sponge layer at 0.3 mb (about 55 km). NOGAPS will then be extended to 48 levels, with a sponge layer at 0.01 mb (near the mesopause at about 80 km). A final extension will place the sponge layer at about 110 km, so that the dynamics of the entire middle atmosphere will be below the sponge layer.

NOGAPS contains modules to compute the radiative heating and cooling of the stratosphere by ozone. The ozone field is presently taken from climatology. After the extension NOGAPS will assimilate daily measurements of the ozone field, and will also combine those measurements with a photochemical model to forecast the ozone field (and hence the radiative heating and cooling rates) at later times.

Two of the major tasks in extending NOGAPS are: (1) the development of algorithms to assimilate satellite-based measurements of ozone, including a quality-control algorithm that takes into account both the space-time sampling and the quality of the satellite-based measurements, and (2) the development of algorithms to forecast the ozone field at later times. The goal of the experiment to be discussed later in this paper is to provide data for developing and testing these algorithms.

Daily measurements of middle-atmospheric ozone will be needed operationally by the extended NOGAPS. They will be obtained from the NPOESS Ozone Mapping and Profiler Suite (OMPS).

III. OMPS

OMPS is a suite of instruments that will measure near-UV, VIS or near-IR sunlight scattered by the Earth's surface or limb. OMPS instruments will measure the ozone total column and the vertical distribution of ozone.

Measurements of scattered sunlight are possible only on the day side of each orbit. Supplementary NPOESS measurements of the ozone total column will be provided by processing NPOESS Cross-Track Infrared Scanner (CrIS) measurements of ozone emission at 9.6 μm, on the night side as well as day side of each orbit. Present plans call for OMPS to be placed on the NPOESS platform having a descending-node equator-crossing time of 13:30, and for CrIS to be on the same 13:30 NPOESS platform as OMPS.

The OMPS instruments are described in detail in [5], and their expected performance is described by [6]. For present purposes it suffices to know the OMPS Nadir Total Column instrument will be an improved version of the Total Ozone Mapping Spectrometer (TOMS) series of instruments [7], the Nadir Profile measurement will be an improved version of the Solar Backscattered UV (SBUV and SBUV/2) series of instruments [8], and the Limb Profiler will be an improved version of SOLSE/LORE [9].

IV. Fusion of Sparse Presently Available Ozone Data

Prior to the availability of OMPS data during the NPOESS era, OMPS-like global ozone fields are required for the development and testing the extended NOGAPS. To obtain this data we have proposed an early flight of OMPS, known as OMPS-AE (OMPS Assimilation Experiment). At the same time, we are developing methods of combining sparse ozone measurements from present space-based solar-occultation instruments to estimate realistic 3D global ozone fields. On each isentropic surface, the satellite data is used to establish the current correlation between ozone mixing ratio and potential vorticity (as provided by a national meteorological service; in the present case, by the United Kingdom Meteorological Office). Then the empirical correlation is used with the same global field of potential vorticity to provide a global estimate of the ozone mixing ratio on that potential surface [2]. Fig. [1] shows a result of this approach, combining the ozone profiles from the POAM III, SAGE II, and HALOE satellite measurements. Simulating OMPS' sampling of the estimated 3D global ozone field yields data that can be used in data assimilation experiments, and also for refining the OMPS algorithms.

V. Summary

Longer-term tropospheric weather forecasts will require the assimilation of daily data on stratospheric ozone by numerical weather prediction codes. NOGAPS, DoD's principal tool for global weather forecasting, is currently being readied to use ozone data from NPOESS when those data becomes available operationally. DoD will be obtaining operational data on stratospheric ozone from NPOESS OMPS, which will provide improved measurements of the ozone total column and vertical distribution as compared to TOMS, SBUV/2 and SOLSE/LORE. To support and validate the extension of NOGAPS, OMPS-like data are needed well in advance of the launch of the first NPOESS OMPS. To obtain this data DoD is seeking to fly OMPS-AE, and is also developing methods of estimating realistic 3D global ozone fields from presently available satellite data. The OMPS-AE data and the estimated 3D ozone fields will both be used in developing the extended version of NOGAPS.

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